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PARALLEL GAP WELDING

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Quality Assurance and Reliability Laboratory

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PARALLEL GAP WELDING

By

A. M. Pasciak

ABSTRACT

This report presents general information and fundamental requirements of parallel gap welding of low power electronic microcomponents to weldable printed wiring boards.

ELECTRICAL ANALYSIS SECTION
ELECTRICAL TEST AND ANALYSIS BRANCH
ANALYTICAL OPERATIONS DIVISION

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April 3, 1967 IN-R-QUAL-67-6

PARALLEL GAP WELDING

By

A. M. Pasciak*

SUMMARY

Written primarily to familiarize cognizant personnel with the nature and requirements of parallel gap welding, this document covers aspects of the subject from the basic fundamentals of welding through process control.

Parallel gap welding was developed to meet a very specialized need, that of reliably connecting the gold plated Kovar leads of flat pack electronic packages to Kovar laminated printed wiring boards. The composition of Kovar provides the resistance required to generate welding temperatures when subjected to a high intensity current for a short period of time.

Discussed also are types of equipment available, development of welding parameters, methods of inspection, the role of receiving inspection, and the training of welding personnel.

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SECTION I. INTRODUCTION

The advent of subminiaturized integrated circuit and microcircuit components has presented challenging interconnection problems to the electronic packaging field. Where 60 to 120 interconnections per cubic inch were made in standard welded modules, there now exists the requirement of making approximately 1000 interconnections per cubic inch. The usage of flat pack configuration has become quite widespread, and packaging experts predict that flat packs because of their diminutive size and compatible configuration will become a standard for use in the space programs. The problem of joining the flat packs to circuitry of printed wiring boards has been greatly alleviated by a technique known as parallel gap welding. Research and development of this process have shown the reliability of connections made using this technique to be encouragingly high. It must be pointed out that while parallel gap welding is not a "cure-all" to all interconnection problems, it is a method of joining the microcircuitry connections with proven reliability.

Parallel gap welding is limited to gold-plated alloys composed of iron, nickel, and cobalt. Material composition, plating requirements, and lead sizes are specified in Specification MSFC-SPEC-270. Requirements for iron-cobalt clad laminated plastic sheets are specified in Specification MSFC-SPEC-455, and the procedure for parallel gap welding is specified in Procedure MSFC-PROC-429.

SECTION II. FUNDAMENTALS

Welding is defined as the joining of two materials by the application of heat and/or pressure at the interface of the materials. The process to be discussed here is the parallel gap welding process. Parallel gap welding is one process of a number that have been, or are now being, investigated as a means for interconnecting electronic components. These processes include laser welding, ultrasonic welding, electron beam welding, and percussion welding.

Parallel gap welding is a resistance welding process wherein the inherent resistance of the materials to the flow of electric current is employed to generate the required heat for welding. Basically, the materials to be welded are placed under two electrodes which exert pressure on the materials. A high intensity current is then passed through

the electrodes and the materials to be welded for a controlled length of time. The current flowing through the resistance of the materials generates heat which produces the weld.

A. JOINING MECHANISM

The joining mechanism of welding may be classified as either a fusion or a forging action. The fundamental difference between these two mechanisms is the temperature at which the joining weld occurs. The heat generated is a function of the thermal and electrical characteristics of the materials to be welded. These characteristics govern which joining mechanism occurs during parallel gap welding. Figures 1 and 2 illustrate the two basic welds.

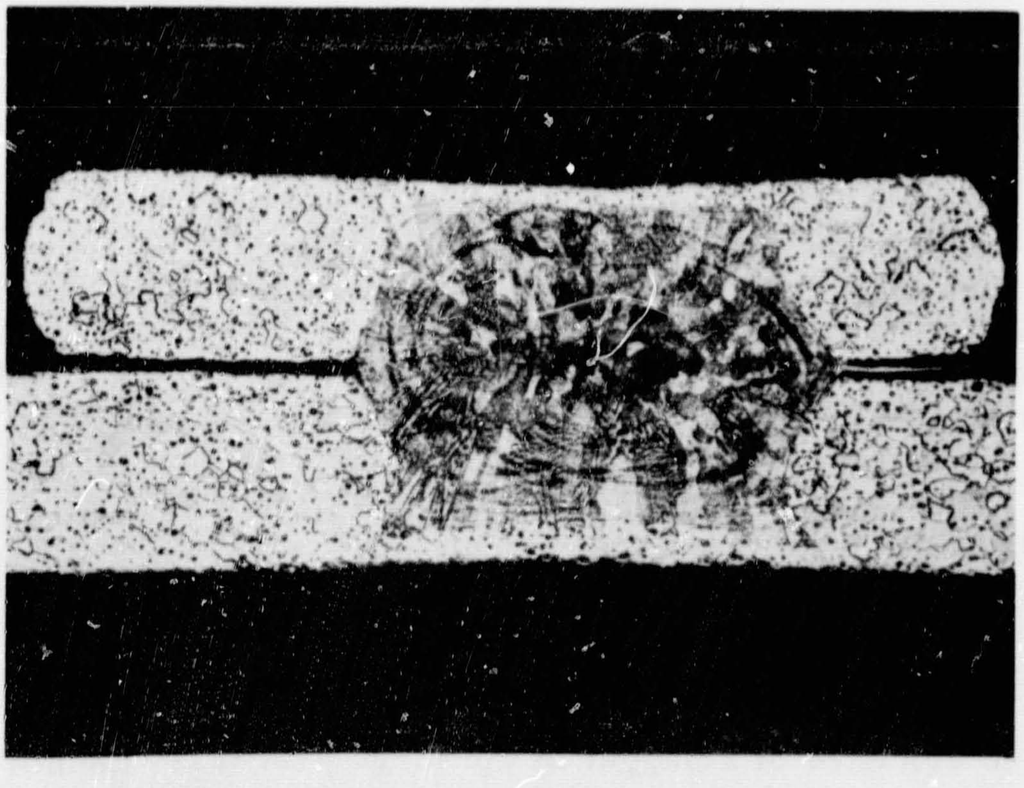


Figure 1. Fusion Weld

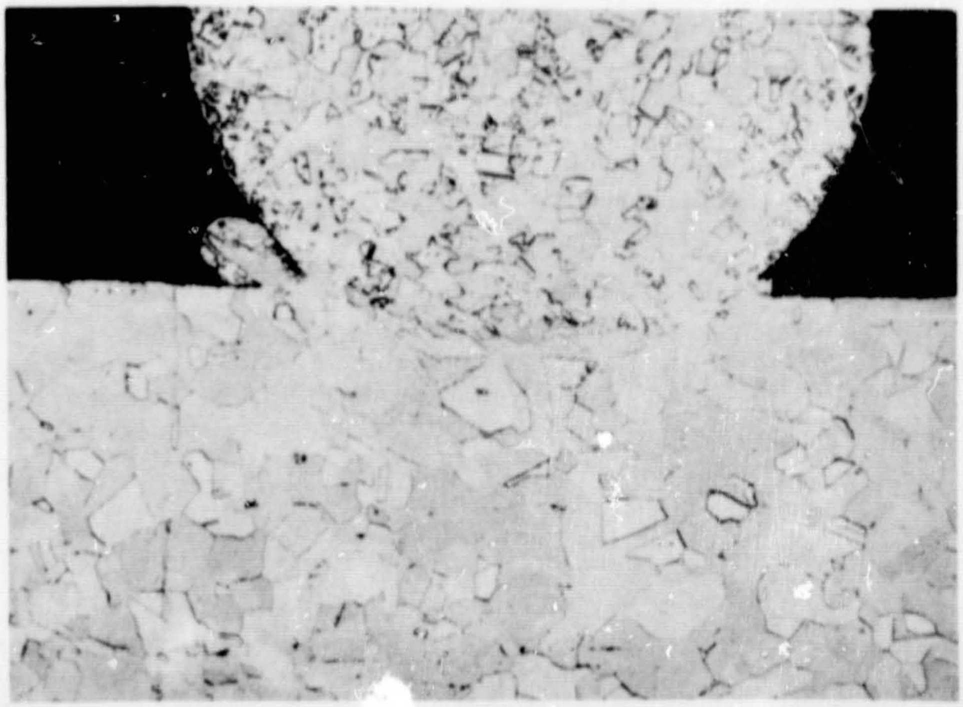


Figure 2. Forge Weld

A fusion weld occurs when the temperature is high enough to cause melting of the weld materials at the point of interface. The molten materials are confined within the weld materials and upon cooling solidify to a cast structure called a "nugget" which binds the materials together. Other metals and materials such as iron, steel, and nickel exhibit this type of weld.

The forge weld takes place when the temperature reached is not high enough to cause melting, but is high enough to cause the materials to reach a plastic state. The pressure exerted by the electrodes forces the materials into intimate contact and the proximity of the atoms of the two materials at the interface causes a solid-state bond. There is no evidence of a nugget in the forge process. Copper and other metals possessing low resistivity and high thermal conductivity are joined by this type of weld due to the difficulty of localizing the heat at the interface.

Of the two basic welds, the fusion weld exhibits greater strength and is more desirable. However, the nature of the materials encountered in resistance welding electronic components is such that most welds are of the forge type.

The typical weld joint achieved in parallel gap welding can be classified as a "braze". This braze weld is basically a result of a lower melting point filler material in the joint. That is, the lower melting point of the gold plating, in relation to Kovar materials, acts as an interfacial bond between the lead and conductor. This wetting of the material usually penetrates into the grain of the parent materials being joined, but with little or no fusion of the base or parent materials.

Figure 3 shows parallel gap welded Kovar lead and conductor bonded together by the fused gold plating.

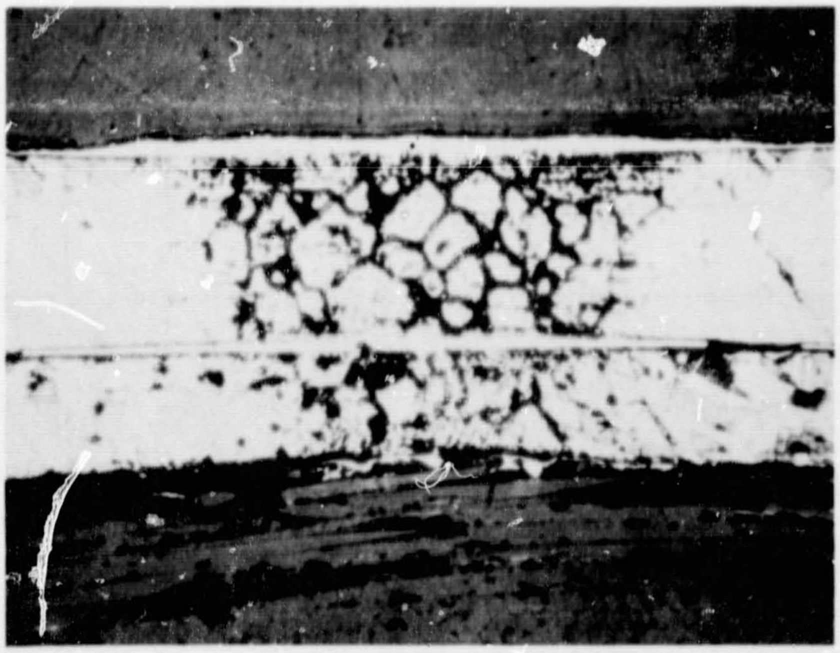
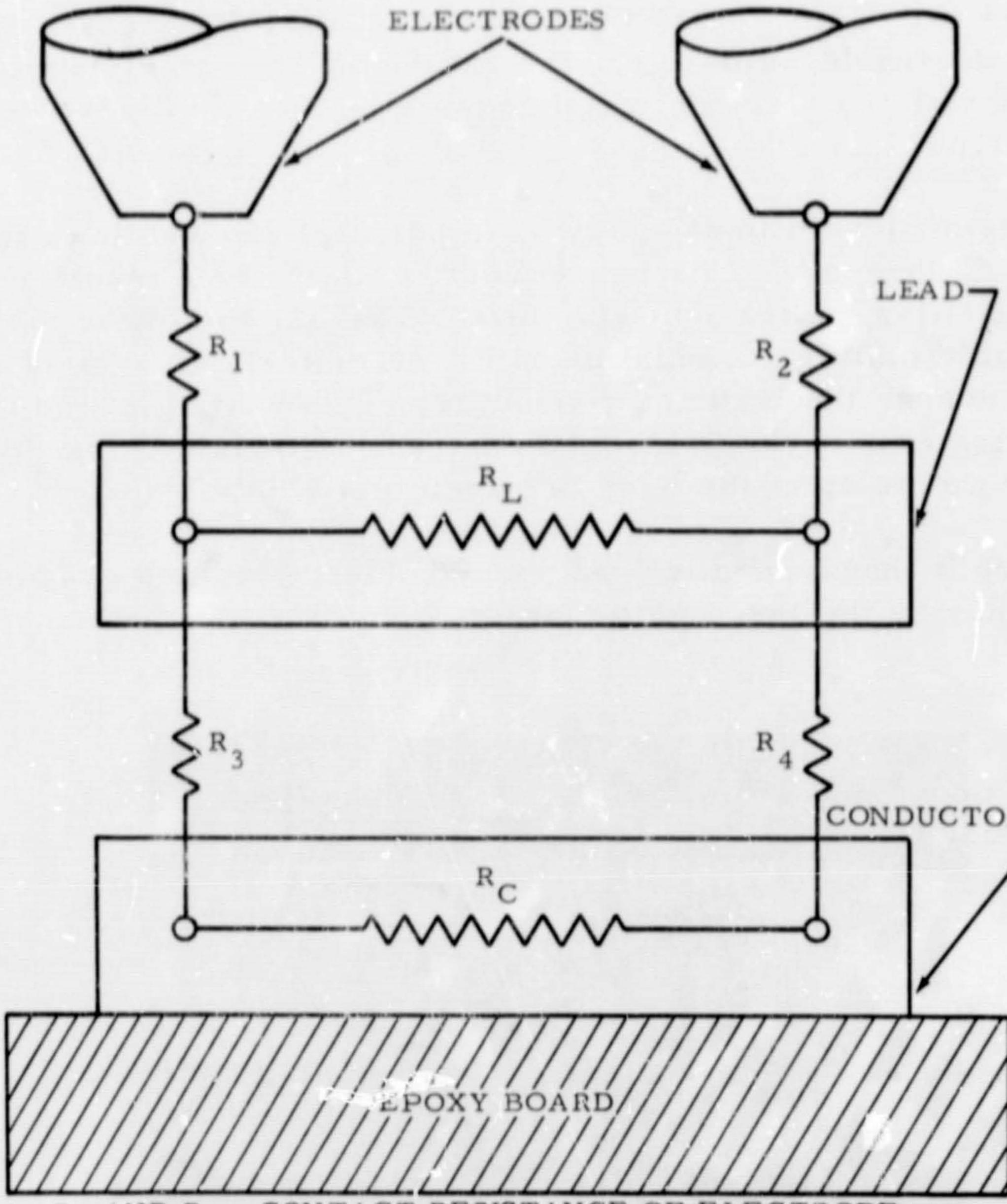


Figure 3. Brazed Weld

B. RESISTANCE OF THE PARALLEL GAP WELD CIRCUIT

The heat generated at any point in the weld circuit will be directly proportional to the resistance and current flow at that point. Heat generated anywhere but at the place of the weld is wasted energy. Therefore, all resistance of the weld circuit, other than at the point of the weld, should be minimized. All the resistances except those shown in figure 4 can be eliminated in the analysis of the weld circuit.



R_1 AND R_2 - CONTACT RESISTANCE OF ELECTRODE
R_3 AND R_4 - CONTACT RESISTANCE OF UPPER AND LOWER WORK PIECES
R_L - RESISTANCE OF LEAD
R_C - RESISTANCE OF CONDUCTOR

Figure 4. Resistance of Parallel Gap Welding

A number of factors will influence the resistance of the contact areas. The resistance of zones R1, R2, R3, and R4 varies with electrode pressure, cleanliness, resistivity, geometry of the electrodes, and the materials. Resistance of R_L and R_C will also vary with gap space.

NOTE: Resistances within equipment are design factors. In a well designed machine, these resistances will be minimized.

C. ELECTRODE PRESSURE

The pressure exerted by the electrodes on the materials serves three main functions:

a. Acts as a holding fixture to keep materials in position.

b. Minimizes resistance between the two materials under the electrodes.

c. Provides forging during metal solidification so that material shrinkage will not promote cracking.

D. TIME

The equation for heat generation shows that the heat produced is proportional to the time duration of current flow. Thus, time duration must be controlled to produce consistent welds. In the case of stored energy equipment, the time is fixed and may be considered a constant. The pulse width of most automatic type microelectronic gap welding machines is in the range of 1 to 10 milliseconds, although equipment is available with longer pulse durations.

E. HEAT GENERATION

The heat to produce the weld is generated by a high intensity current flowing through the resistance of the materials to be welded.

Current flowing in a resistive circuit generates heat which may be expressed by:

$$P = I^2R$$

where P = power (watts), I = current (amps), and R = resistance (ohms).

This equation gives an instantaneous value and does not take into consideration the element of time. Taking time into consideration, the equation becomes:

$$W = .24\ I^2RT$$

where W = energy (calories), I = current (amps), R = resistance (ohms), T = time (seconds), and 0.24 is the conversion factor.

Using this formula, the amount of energy generated by a given quantity of current flowing through any specified value of resistance for a precise length of time may be computed.

F. CURRENT

The current flowing in the weld circuit plays the major role in the generation of heat in the materials to be welded since the heat produced is proportional to the square of the current. However, the amount of current flowing in the weld circuit is a functional result of the weld circuit resistance, applied voltage, and time. The idealized distribution of current in the lead and conductor is shown graphically in figure 5.

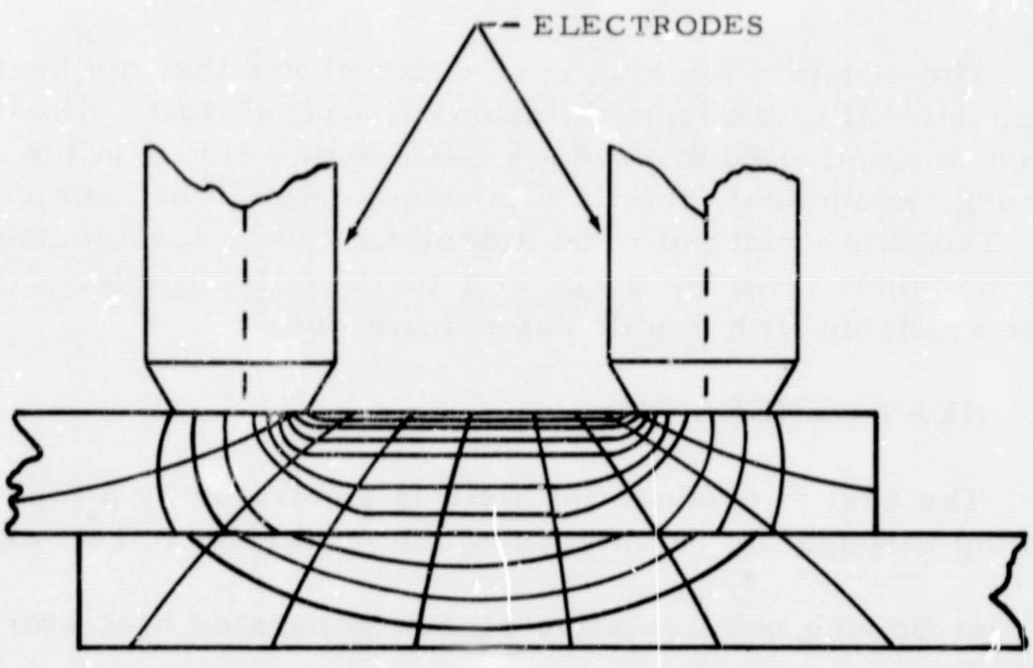


Figure 5. Equipotential and Current Flow Lines in the Gap

G. RESISTANCE DYNAMICS

The resistance of the lead and conductor materials are functions of their temperatures during the welding process. During welding, the temperature of the lead will increase at a faster rate than will that of the conductor because of the greater current flow in the lead, as illustrated by the current lines in figure 5. Thereupon, a redistribution of current flow occurs, i.e., less current flows in the lead material and more through the conductor, thus increasing the rate of heating of the conductor.

Both materials will then reach an elevated temperature high enough to melt the gold plating. A weld (or braze) is accomplished at their interface. Cleanliness of materials and thickness of gold plating is also a governing factor of resistances at the weld zone. However, these areas are covered in section III, Materials, and section VII, Process Control.

The temperature profile of the weld zone is typified in figure 6. The actual temperature distribution across the electrode gap shows a narrower profile than the ideal because of the heat sink effect of the electrodes. For this reason the actual weld area will always occupy an area less than the area in the electrode gap.

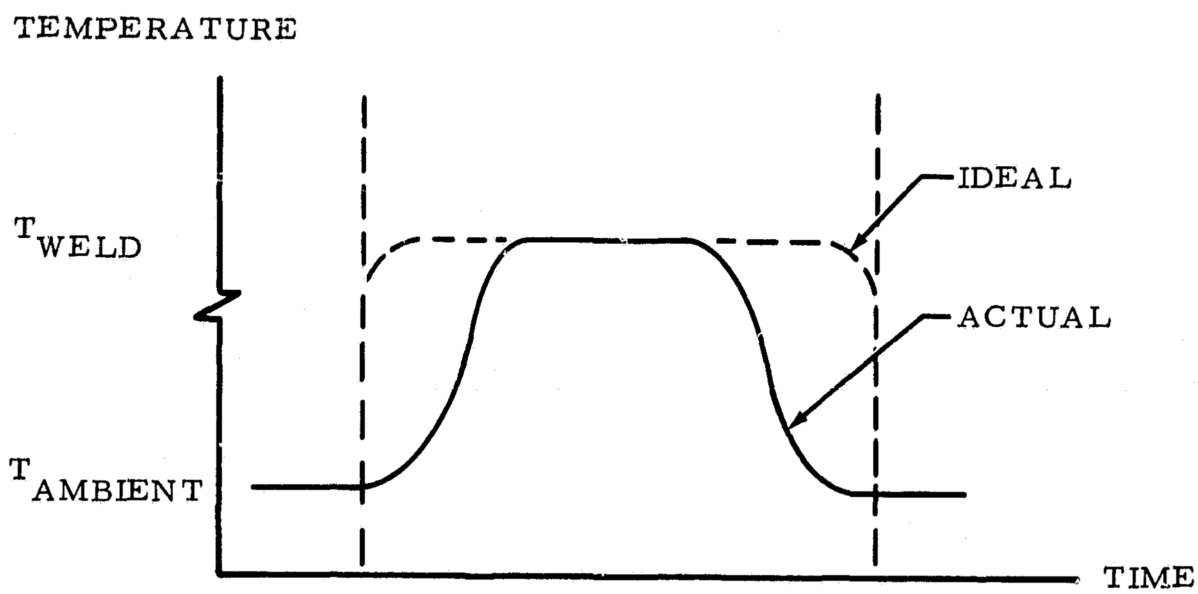


Figure 6. Temperature Profile for Parallel Gap Weld

SECTION III. MATERIALS

The specified material for use in parallel gap welding is limited to an alloy of iron, nickel,and cobalt composition, such as manufactured under trade names of Kovar and Rodar. As previously stated, a good weld is dependent upon the proper amount of heat generated between the electrodes for a controlled duration. Any variation in material size changes the current requirements. For this reason, lead material tolerances must be controlled in order to repeatedly produce acceptable welds.

Gold plating of Kovar enhances weldability in general and is a requirement in parallel gap welding. It is also an excellent aid in visual weld inspection and a good corrosion deterrent. Detailed Kovar material composition, gold plating requirements, and component lead material sizes and tolerances are specified in Specification MSFC-SPEC-270. The requirements for nickel-iron-cobalt clad (type K or Kovar) laminated plastic sheet are specified in Specification MSFC-SPEC-455, while Procedure MSFC-PROC-429 specifies the procedure for parallel gap welding.

The following lead and conductor size combinations are recommended for use as a guide for the proper distribution of heat in the weld zone. The thickness dimension of the component lead is used to determine other dimensions:

Thickness of the lead, $t_L = X$

Width of lead, $w_L = (3.0 \pm 0.4)\ X$

Thickness of conductor, t_C (Weld Pad) $= (0.7 \pm 0.1)\ X$

Width of conductor, $w_C = w_L + 0.003$ to 0.007 inch

A diagram of the above combination of materials is shown in figure 7.

SECTION IV. EQUIPMENT

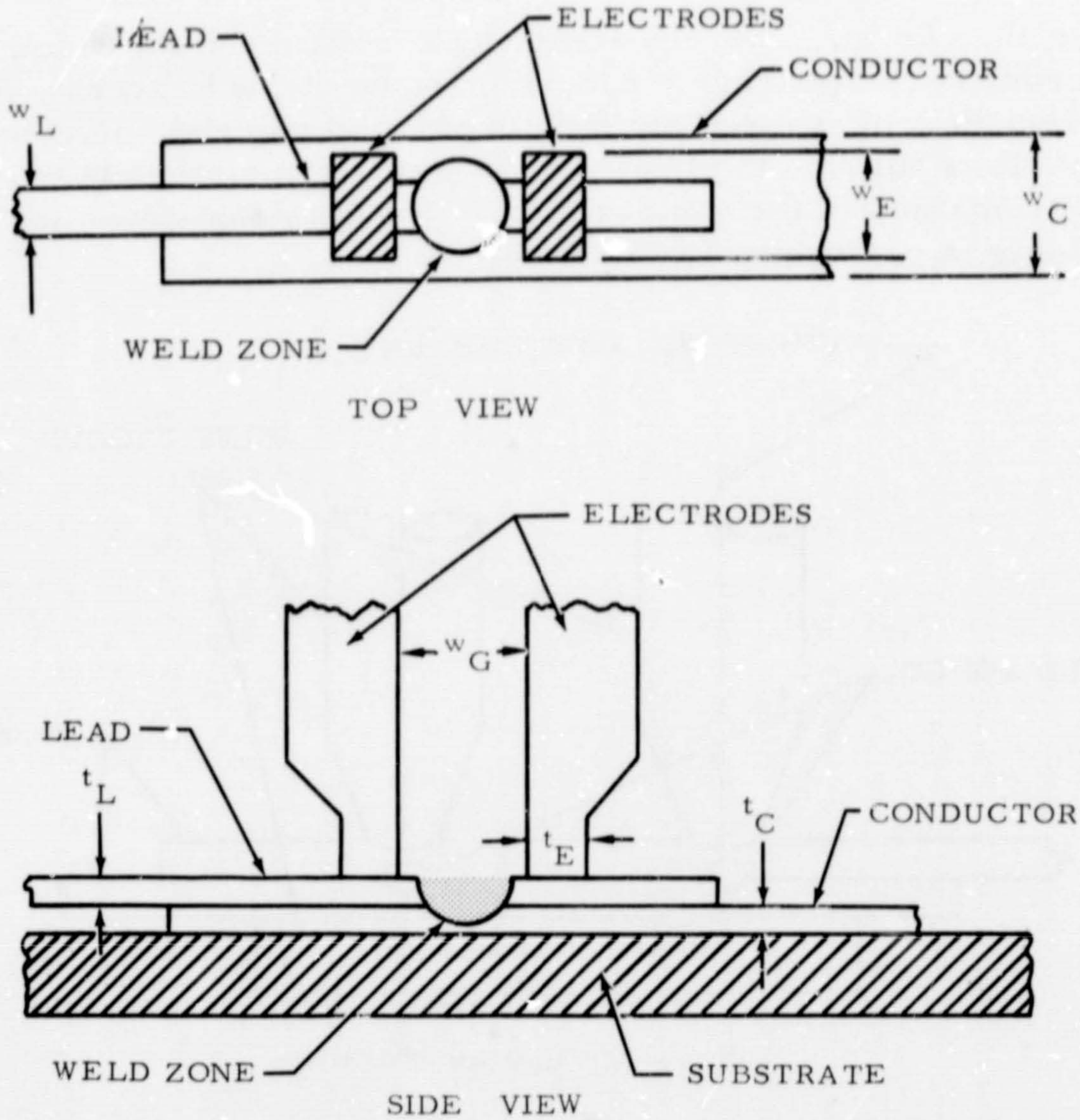
The equipment used for parallel gap welding should conform to the basic requirements:

a. Capability to supply high current of a short duration.

b. Capability to exercise control over pulse duration and current.

c. Capability to exert a controllable force on the materials to be welded.

d. Provide a gap, either air or a solid dielectric material, between the electrodes.



t_E = thickness of electrode tip

w_E = width of electrode tip

w_C = width of conductor

w_L = width of lead

w_G = width of the electrode gap

t_L = thickness of the lead

t_C = thickness of the conductor

Figure 7. Identification of Materials Used in Formulas for Selection of Sizes

Control is accomplished by three main equipment subsystems: electrical system, timing and control system, and mechanical system.

The electrical subsystem is a modified version of a series welder, which has a third electrode completing the electric current path. This third electrode is usually a copper plate of sufficient mass

to shunt the current, thereby achieving a weld at the interface of materials under each electrode. Figure 8 shows the weld zones and the path of current flow in series welding. In parallel gap welding, the weld current flows through the lead and the conductor materials only. The weld is contained in the gap of the two electrodes as shown in figure 9. No welding is performed under the electrodes.

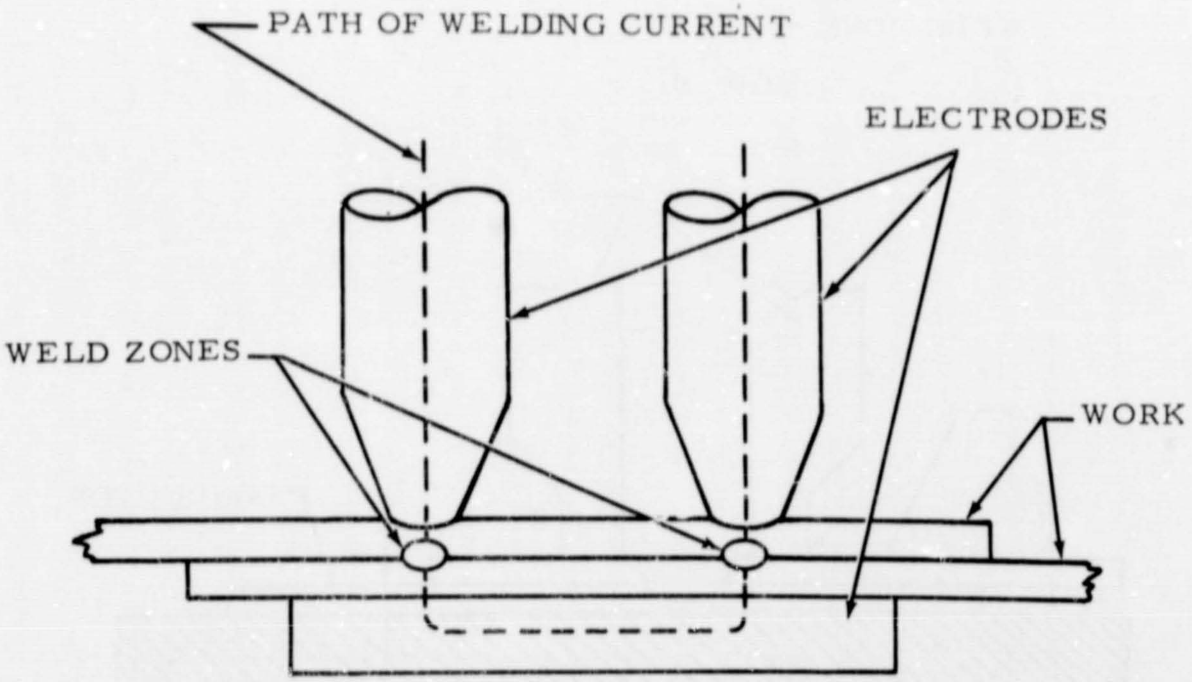


Figure 8. Series Welding

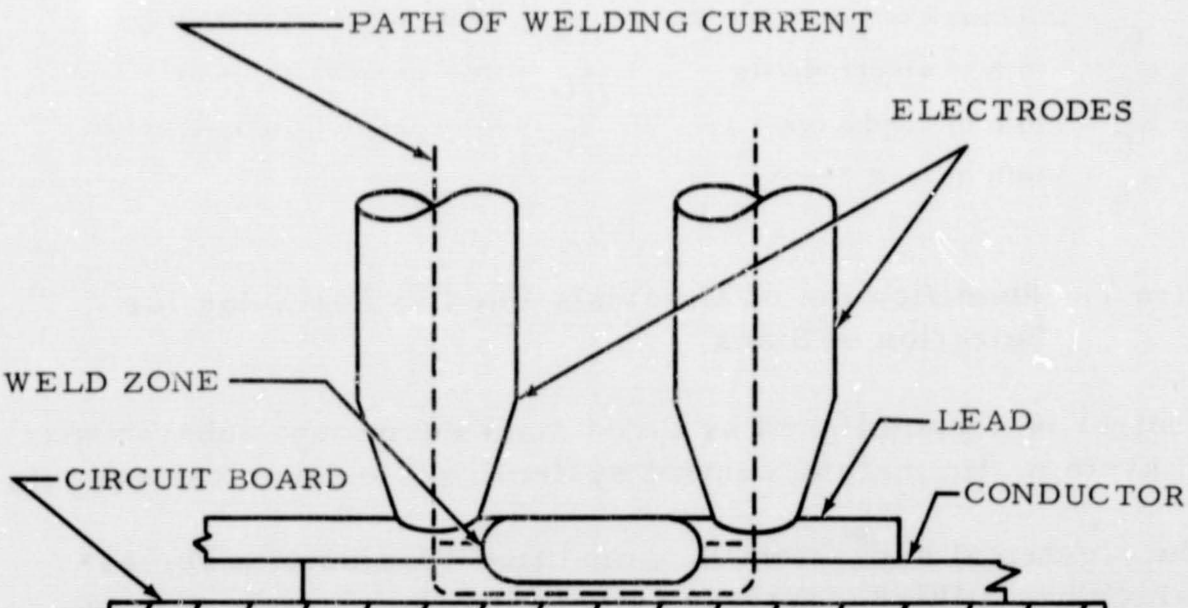


Figure 9. Gap Welding

The timing and control system controls the amount of current delivered to the weld zone and the duration of current flow.

The mechanical system provides pressure to minimize resistance beneath the electrodes and provides a table to hold the materials in position for the weld cycle. It also serves as a means of holding the electrodes.

A. POWER SUPPLIES AND CONTROL CIRCUITS

The current required for welding is developed by the weld transformer in the power supply. There are basically two types of power supplies for developing the current: ac power supply and the stored-energy power supply. The stored energy type power supply is the most widely used in resistance welding programs. This type power supply stores in a capacitor bank electrical energy which can be discharged when current is needed. Storage of the energy is accomplished when the ac line signal is stepped up, rectified, and the resulting high voltage stored in the capacitor bank. The amount of energy stored is varied by varying the capacitor charge-voltage and is expressed by the equation $W = \frac{CV^2}{2}$. The capacitor is discharged through the weld transformer, resulting in a single pulse of current at the weld zone. By increasing the potential of the stored voltage, the pulse amplitude, and, subsequently, the amount of current delivered to the weld zone is increased. The pulse duration is constant and is usually in the range of 1 to 3 milliseconds.

Other variations of stored energy weld systems in use are the electrochemical or storage battery and the single pulse solid-state circuitry. Both systems incorporate an automatic feedback circuit that maintains a constant selected voltage and regulates the duration of the pulse, while still another weld system controls the current constant and varies the voltage as required. Theoretically, parameters are selected and set to the resistance of the materials at their melting point. When this point is reached, the feedback circuit cuts off the pulse, thereby protecting the materials from further melting that could result in a weld "blow-out".

B. WELD HEADS

The welding head and its associated actuating mechanism serves the purpose of holding the electrodes and provide the necessary pressure. The electrode arms provide a controllable gap between the

electrodes. There are several types of weld heads, and each type incorporates a different configuration of electrode holders. One example is illustrated in figure 10. This type of holder is equipped with a micrometer gap adjusting device calibrated in thousandths of an inch. Another type is shown in figure 11. In this type holder, the force of each electrode is independently controlled. However, in order to change the gap setting the electrode holder must be loosened and, with the aid of a thickness gage, repositioned to the desired gap. Still another type accepts only split electrodes.

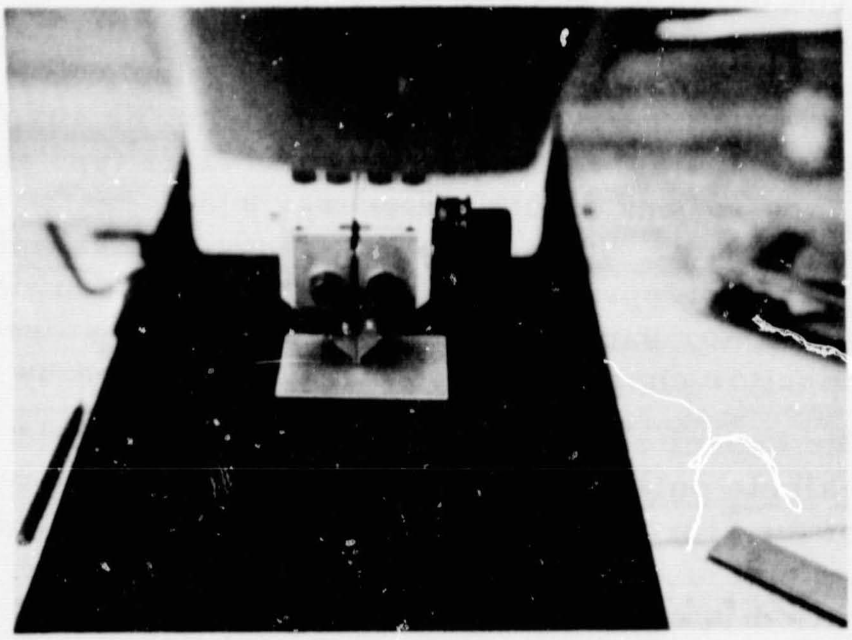


Figure 10. Electrode Holder with Micrometer Gap Adjusting Device

C. ELECTRODES

Electrodes are available in many sizes and compositions and have been categorized into groups by the Resistance Welding Manufacturer Association (RWMA). But for purpose of parallel gap welding, the electrode materials can be limited to group A or copper base alloys. Electrodes of RWMA class no. 2 perform in a satisfactory manner and will suffice as will RWMA class no. 3 electrodes. Unlike spot resistance welding which requires the proper resistivity of each electrode to furnish the proper heat balance at the interface of materials being welded, the electrode requirements for parallel gap welding are: (1) that the resistance under the electrode be kept to a minimum and

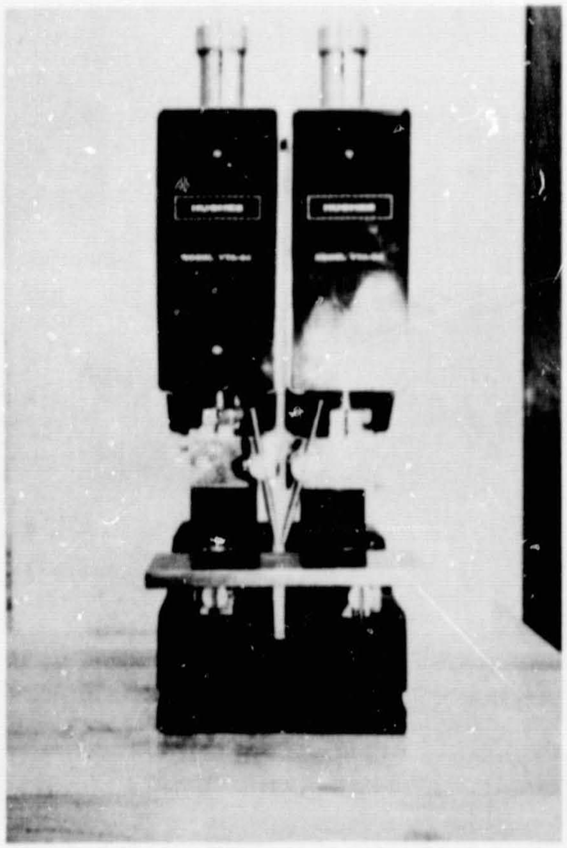


Figure 11. Weld Head with Manual Gap Adjustment

(2) the resistance be localized to that of the materials between the electrodes. Examples of electrode configurations are shown in figures 12 and 13. Electrodes in figure 12 are air gap type and can be adjusted to specified requirements, while the electrodes in figure 13 are bonded to a solid dielectric material of a specific thickness that serves as a gap for the weld zone. This type is commonly referred to as a split electrode. A change to a different gap setting requires electrode replacement with an electrode of a desired dielectric thickness.

SECTION V. DETERMINATION OF OPTIMUM PARAMETERS

In parallel gap welding the heat is dependent upon the resistivity of the materials, whereas in spot welding it is primarily dependent upon contact resistance between the materials being welded. Also, unlike resistance spot welding, sufficient electrode pressure must be applied to the materials to reduce contact resistance to a minimum to permit

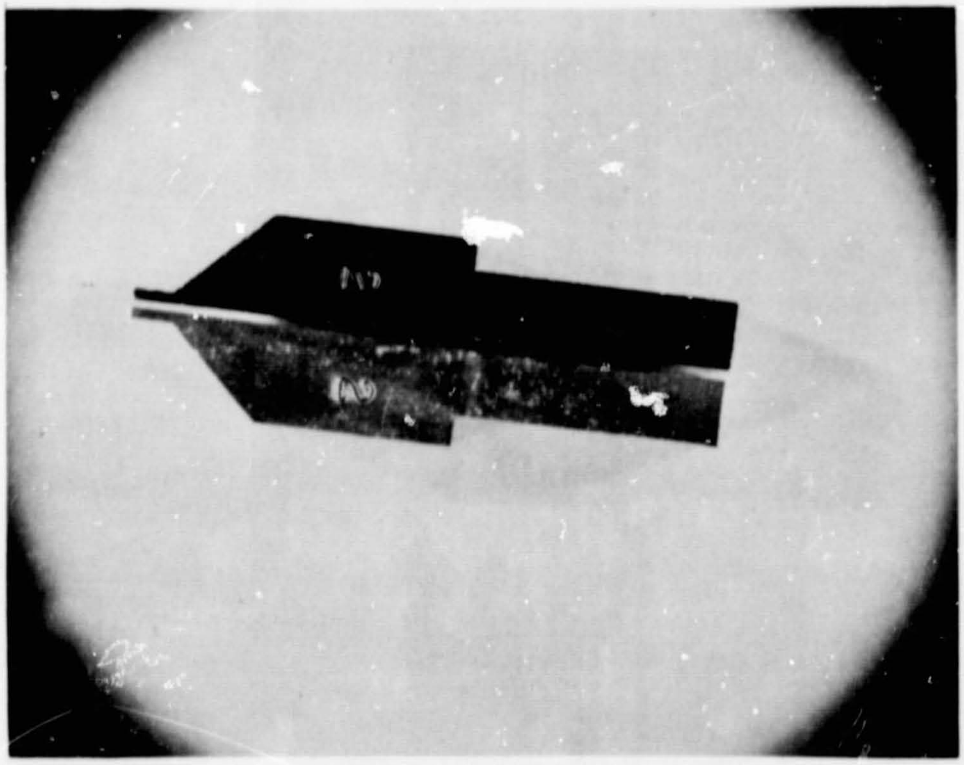


Figure 12. Air Gap Type Electrodes

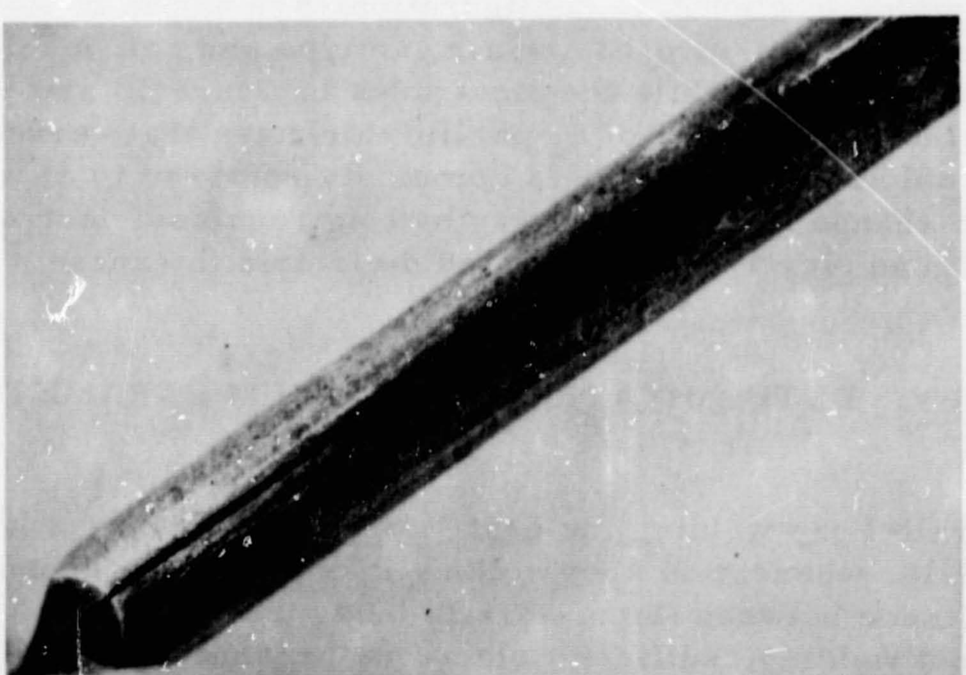


Figure 13. Electrodes Bonded to a Solid Dielectric Material

the heating of the materials between the electrodes only. Heating of materials under the electrodes causes surface fusion of the lead and also material pickup on the electrode tips.

An iso-strength diagram should be prepared to determine: (1) which combination of parameters results in the most consistent welds and (2) welds that exhibit no defects. This diagram is a graphical representation expressing the strength of the weld as a function of voltage, pressure, time, and gap. On the diagram the modulation or time is plotted on the ordinate,and the amplitude or voltage is plotted on the abscissa. Plotting data are generated by selecting increments of voltage at preselected weld pulse time, producing the welds at these coordinate points, and pull-testing the welded specimens. The averaged pull test strength of the welds should then be recorded at the proper coordinate point. Figure 14 illustrates a suggested iso-strength diagram.

In determining optimum parameters, the following approach was found to give satisfactory results. Select an electrode pressure of approximately 4.0 pounds force. Set the modulation or duration of weld pulse at approximately 8 milliseconds (for constant voltage systems), gap at 0.016 inch, the amplitude or voltage below the fusion level of the material between the electrodes.

NOTE: When using spot resistance weld power supply, the pulse duration remains constant and is usually in the range of 1 to 3 milliseconds.

The force and the gap settings should be held constant while developing the iso-strength diagram. Begin making the welds, and after each weld pulse, increase the voltage at selected increments and reweld until a darkened area appears. At this point, begin recording the weld pull strength. As welding is continued at progressively increased voltage, the darkened weld area will increase as will the tensile-shear pull strengths. Continue increasing the voltage and testing the welds until some form of weld defect appears, such as deformation or a blow hole. From the iso-strength diagram, a selection of the optimum parameters is made (at a point that the welds are free of defects and the welds have consistent pull strengths). The selected parameters should then be verified for repeatability. This is accomplished by taking a specified number of weld samples and performing a metallurgical examination on some and pull testing the remainder.

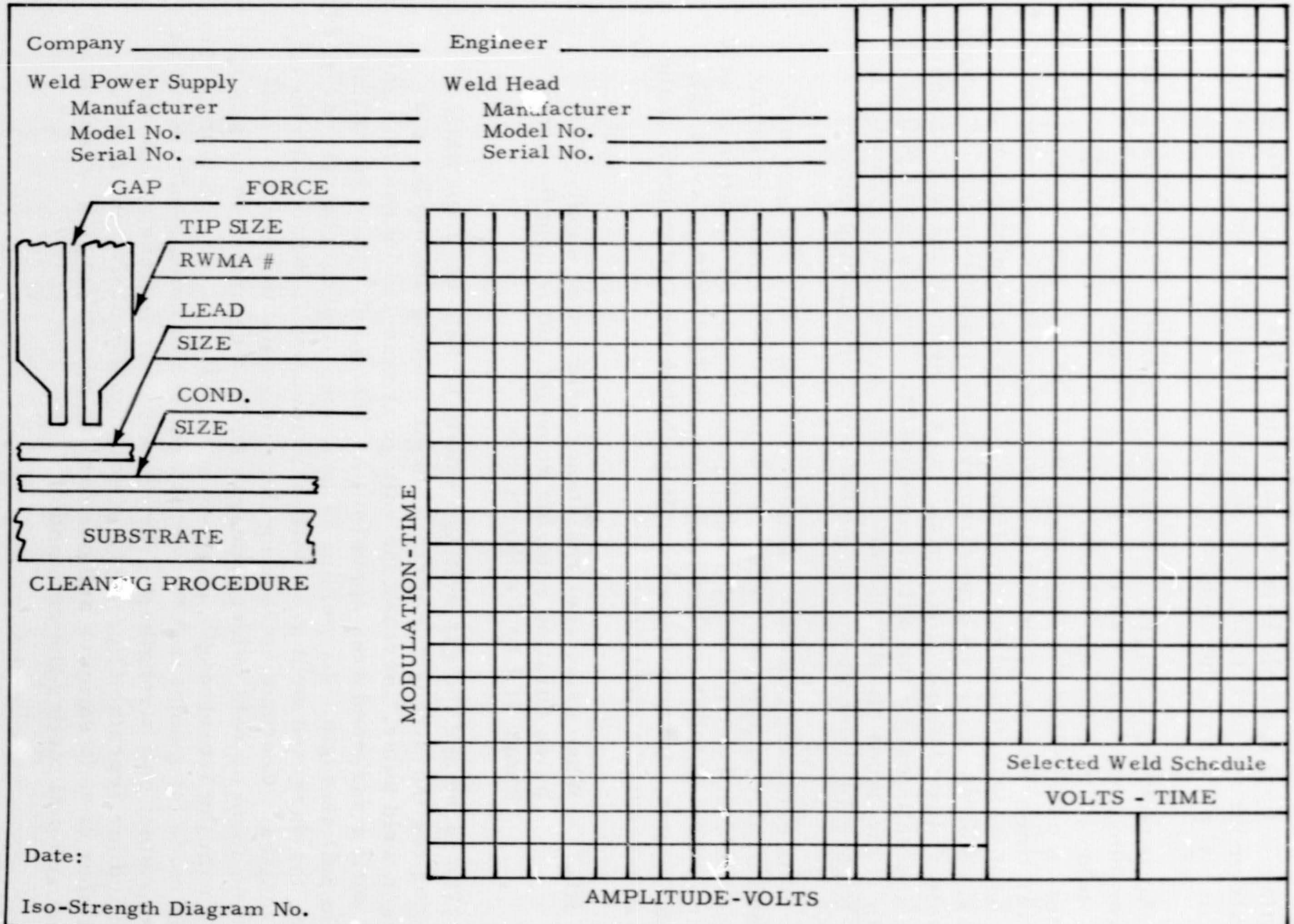


Figure 14. Sample Iso-Strength Diagram

Pull testing of the welds should be accomplished using the tensile-shear pull configuration. A shear pull tester is illustrated in figure 15. The pull testing is performed as follows: A printed wiring board is fastened in a power driven clamp assembly. The lead is fastened in a vise assembly attached to a stationary assembly with a dial indicator. The pull is such that the direction of pull is parallel to both the lead and conductor lengths and away from the stationary clamp.

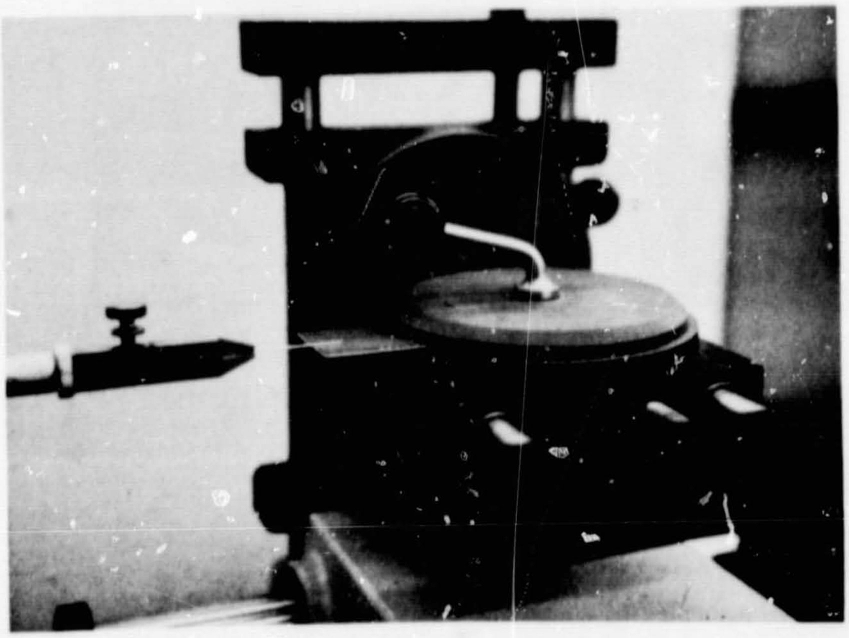


Figure 15. A Tensile Shear Pull Configuration Pull Tester

An alternate method is the substitution of the 90-degree peel-pull test for the shear pull configuration test. A typical peel-pull test is shown in figure 16. The strength requirement for the peel-pull test is that the weld remain intact and that the conductor be lifted or pulled off the substrate. Pull testing in this configuration does not test the integrity of the weld joint but merely whether the weld is stronger or weaker than the bonding of the conductor to the substrate.

SECTION VI. WELD INSPECTION

Parallel gap weld examination is performed in a manner similar to that of other resistance welding. However, with parallel gap welding, greater emphasis is placed on nondestructive inspection.

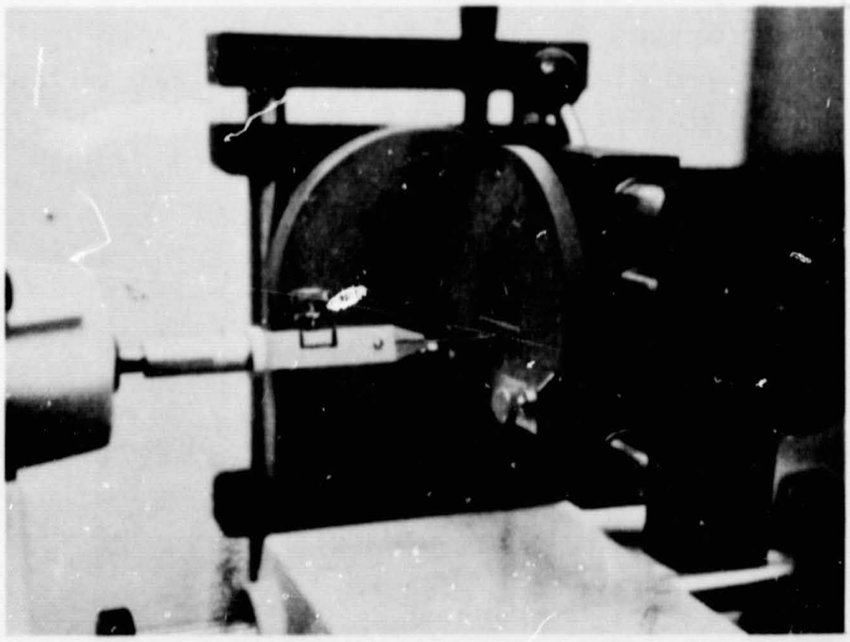


Figure 16. Ninety Degree Peel-Pull Configuration Pull Tester

A. NONDESTRUCTIVE INSPECTION

Visual inspection is still the only satisfactory method employed to properly evaluate a weld nondestructively. Because of the miniature size of the welds, visual inspection should be performed at a magnification of at least 30 power. This power of magnification is necessary to aid the inspector in determining the condition of the weld, both by the presence (or absence) of defects and by the size of darkened gold plating area in the weld zone. See figure 17.

All parallel gap welds exhibit the darkened area caused by heating. An unacceptable weld, aside from darkened area, is one which exhibits one or more of the defects or characteristics described below.

1. Open Weld. An open weld is the result of an attempted weld wherein no bond has been accomplished. This can be due to misfire of welding equipment, the face of electrode being contaminated and not making electrical contact with the lead material, or to an oversight on the part of the weld operator.

2. Offcenter Weld. An offcenter weld is a weld in which the lead material was positioned at the side of the conductor. This unacceptable type of weld is caused primarily by the operator; however,

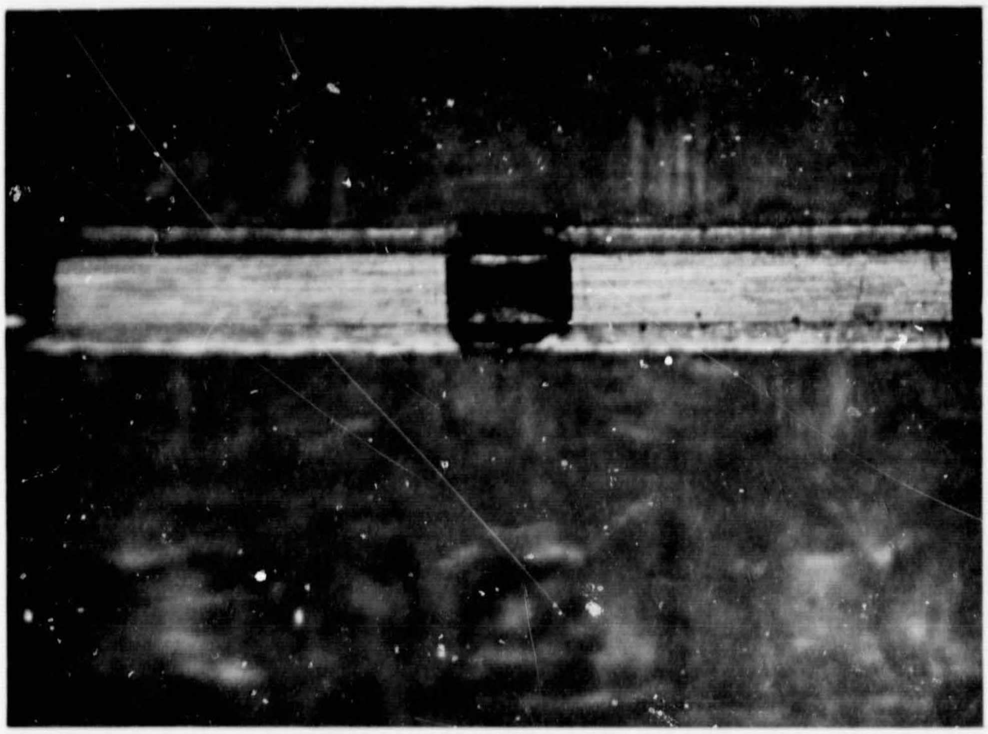


Figure 17. An Acceptable Quality Gap Weld

some weld heads are designed with electrodes mounted on a pivot such that the electrode tips move or "walk" and compensation for their movements must be anticipated when placing material over the conductor. See figure 18.

3. Cracked Weld. Any weld which exhibits a crack in the weldment is a cracked weld. Cracks usually appear across the weld and are caused by excessive heat. See figure 19.

4. Deformed Weld. A deformed weld is one in which the geometry of the material has been reduced. This condition is also referred to as "necking" and is caused by excessive heat. See figure 20.

5. Metal Expulsion. A weld which exhibits excessive bulging in the form of a "splash", or deposits of metal fragments in the weld area has undergone metal expulsion. Metal expulsion is the result of excessive heat. See figure 21.

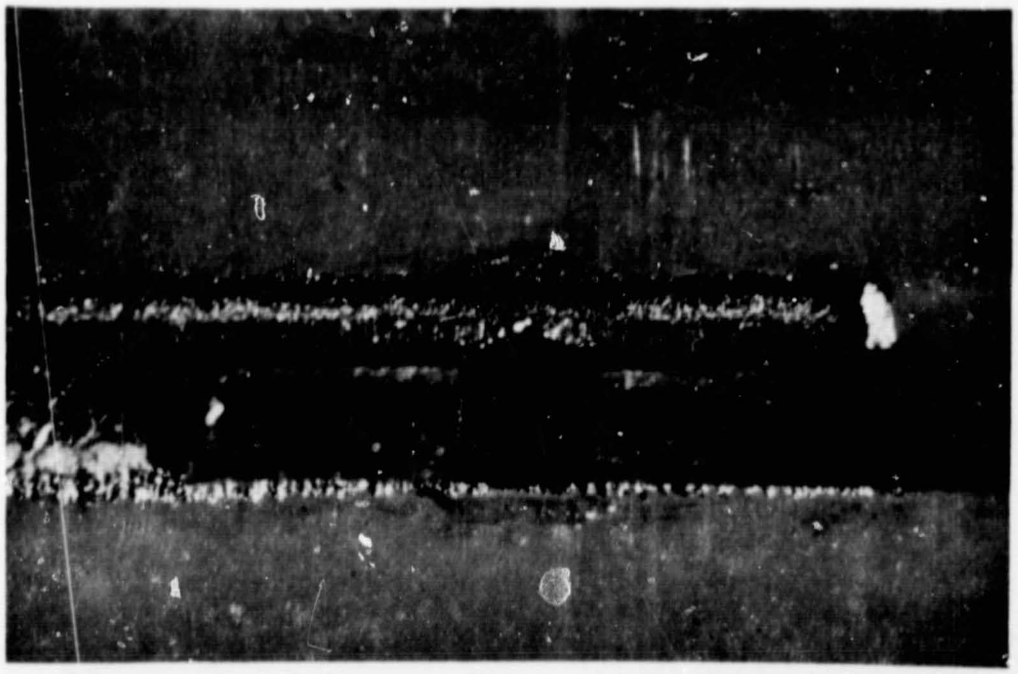


Figure 18. An Offcenter Weld

Figure 19. Cracked Weld (Also Showing Metal Expulsion and Deformation)

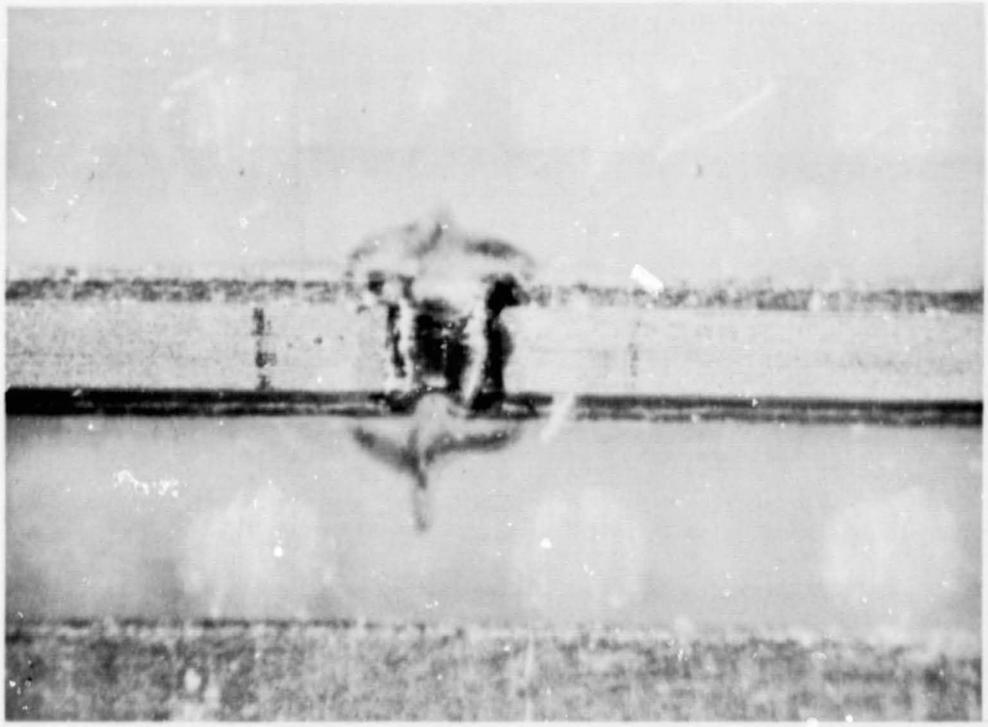


Figure 20. Deformed Weld

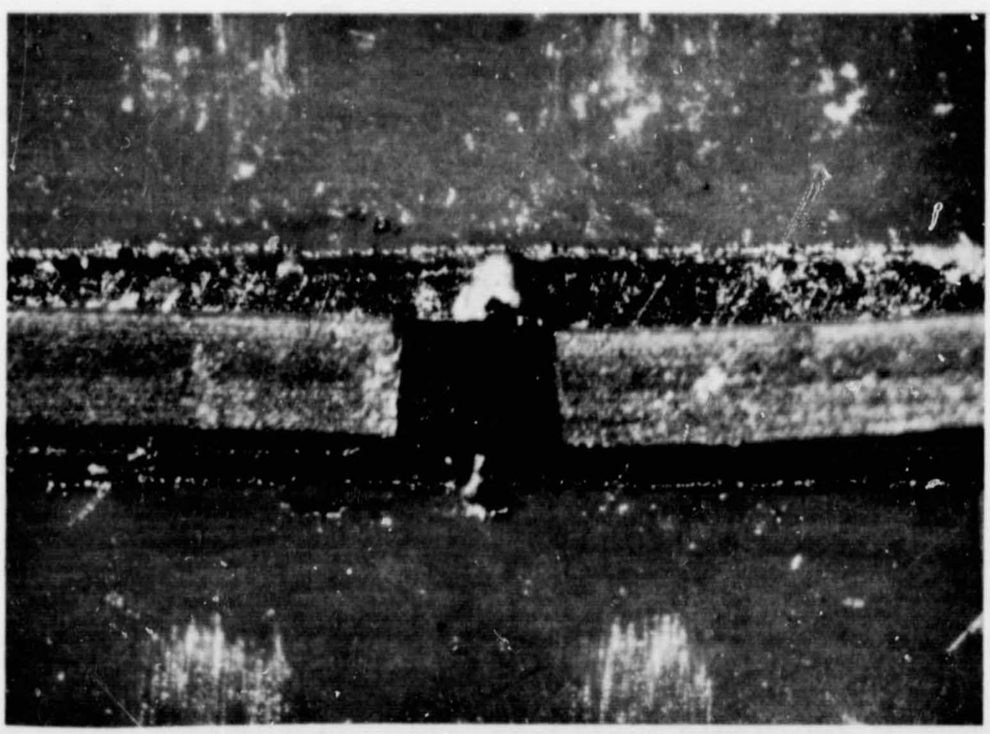


Figure 21. Metal Expulsion

6. Blow Hole. Holes or voids are usually present along the interface of the welded materials. Blow holes result from the formation of gases caused primarily by the presence of contaminants, excessive heat, or exuding molten epoxy. See figure 22.

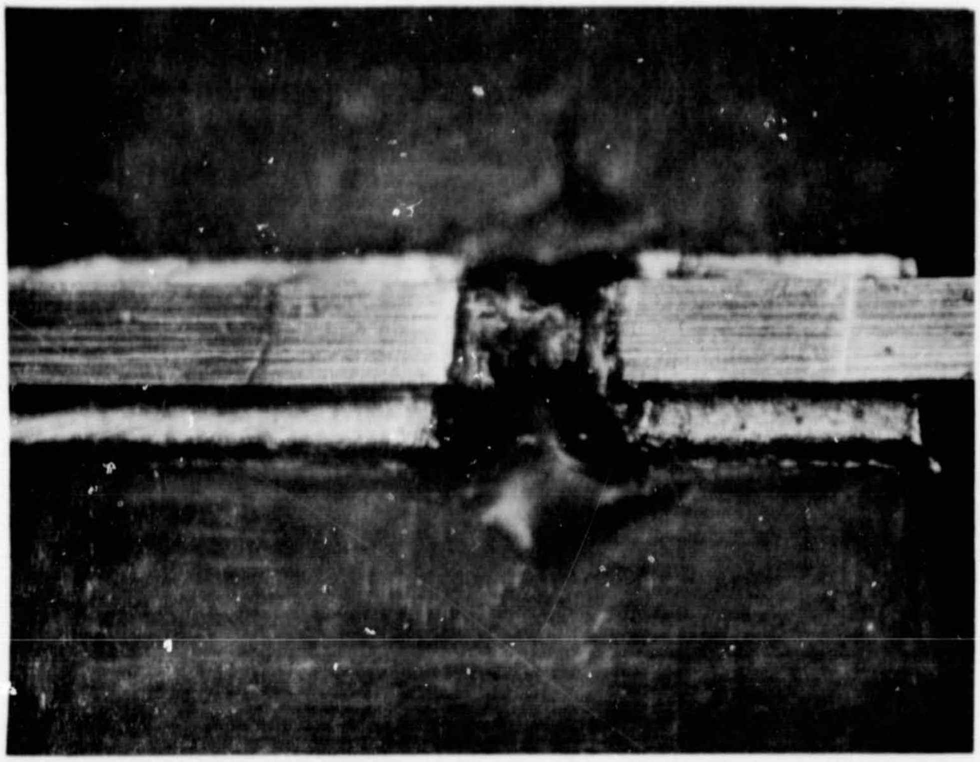


Figure 22. Blow Hole

7. Pitted Weld. A weld that exhibits pits at the interface of the electrodes and the component lead is termed a pitted weld. This condition is the result of insufficient electrode force. Remedial action must be taken immediately to prevent repetition of this condition. In some cases, electrodes "sticking" to the lead surface can cause the welded materials to be lifted off the substrate as the electrode force is released.

8. Insufficient Weld. An insufficient weld is one in which inadequate diffusion or brazing action has occurred. This condition is easily detected by the absence of or the diminutive size of the darkened area in the weld zone. See figure 23. Both welds were performed at the same gap setting, but the weld on the right exhibits a smaller darkened area. This condition indicates inadequate heat to properly weld the materials together.

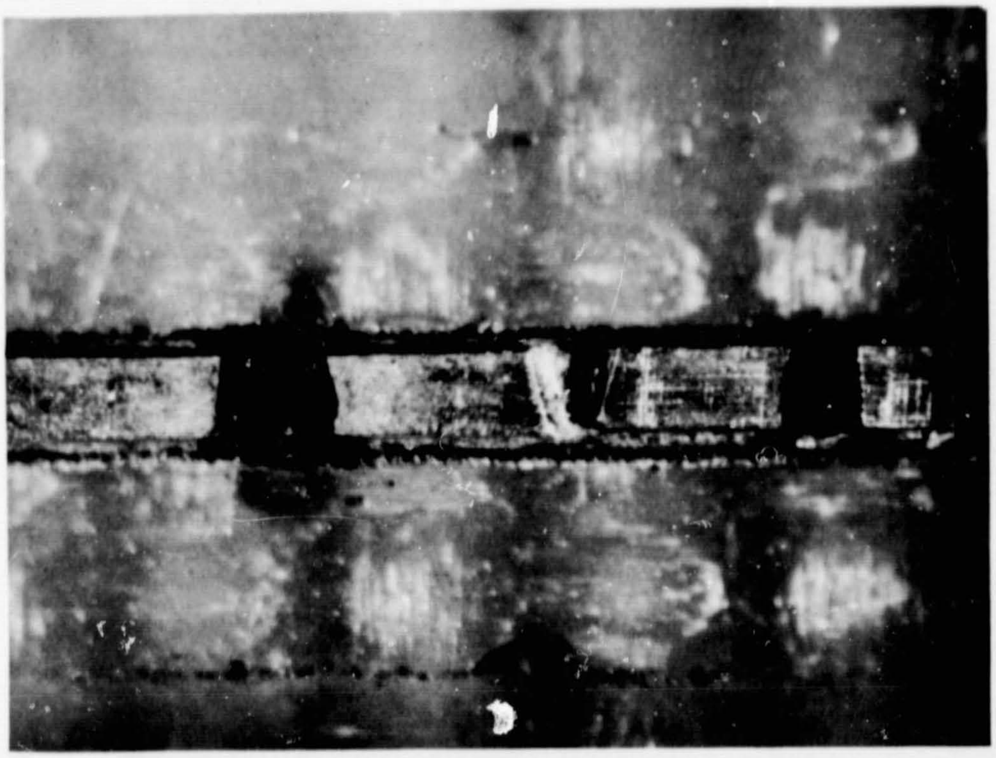


Figure 23. Welding Performed at Same Gap Width (Insufficient Weld on the Right)

9. Misaligned Weld. A weld in which a lead is misaligned and not fully supported by the lower conductor, or a weld wherein the electrodes did not make full contact across the full width of the lead, is defined as a misaligned weld. Figure 24 is an example of improper lead alignment.

A defective weld will usually exhibit more than one defective condition. Figure 19 exhibits a deformation, a blow hole, metal expulsion, and a crack.

B. DESTRUCTIVE INSPECTION

Destructive inspection is made by either a pull-test or metallurgical examination. Since the conductors are an integral part of the printed wiring board, pull-tests and metallurgical examination can be performed only on similar materials. Pull-tests are beneficial, supplying quantitative data about the parameter requirements. They are also used as a check on the weld system operating condition.

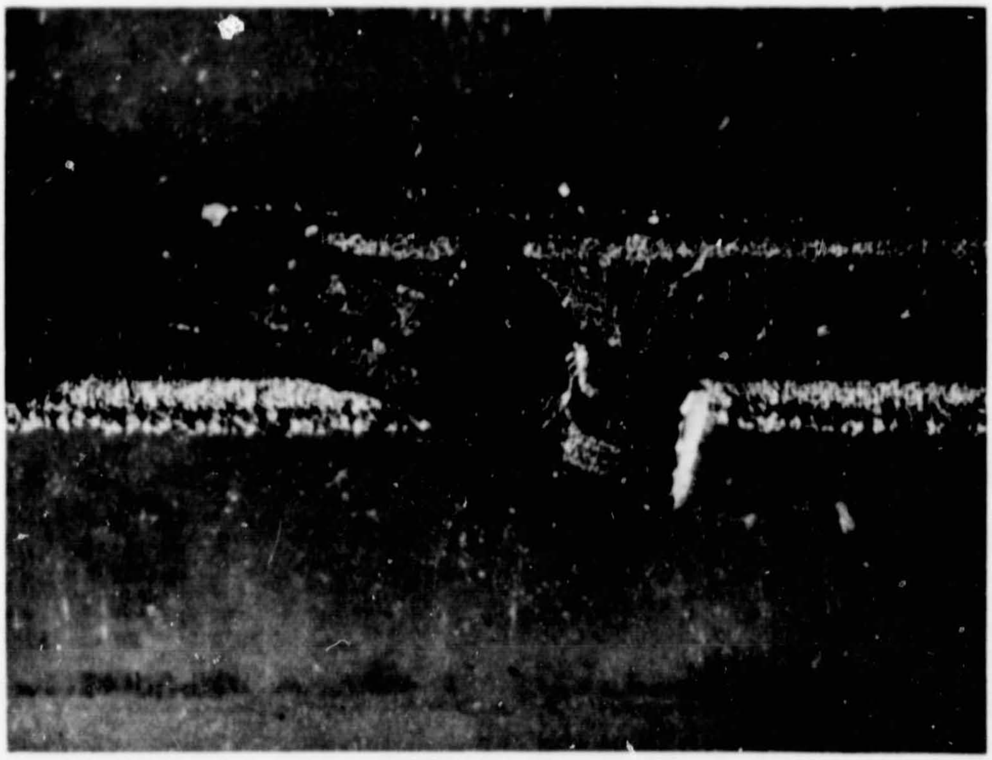


Figure 24. Misaligned Weld

C. METALLURGICAL EXAMINATION

Metallography is still the only analytical technique available for evaluating the quality of the weld itself. Metallographic examination reveals the structure of the interior of the weld and enables the observer to determine the quality of the weld by its type, the amount of fusion or forging, and by defects present within it. However, a skilled metallographer is required to interpret photomicrographs.

After the sample is encapsulated, it is subjected to a series of precision grinding and polishing operations. The free surface and disturbed crystalline layers are then removed by an etching process which will reveal the true structural characteristics of the weld. Thickness of gold platings, type of weld, or discrepancies within the weld can be determined by metallographic analyses. These analyses and interpretations, when performed by a qualified metallurgist or metallographer are valuable and rewarding. Welds used for metallurgical evaluation should be produced on weld systems at production parameter settings.

These settings will verify the adequacy of the weld parameters as well as the performance of the machine to repeatably produce reliable welds. Figures 25 and 26 are photomicrographs of acceptable welds.

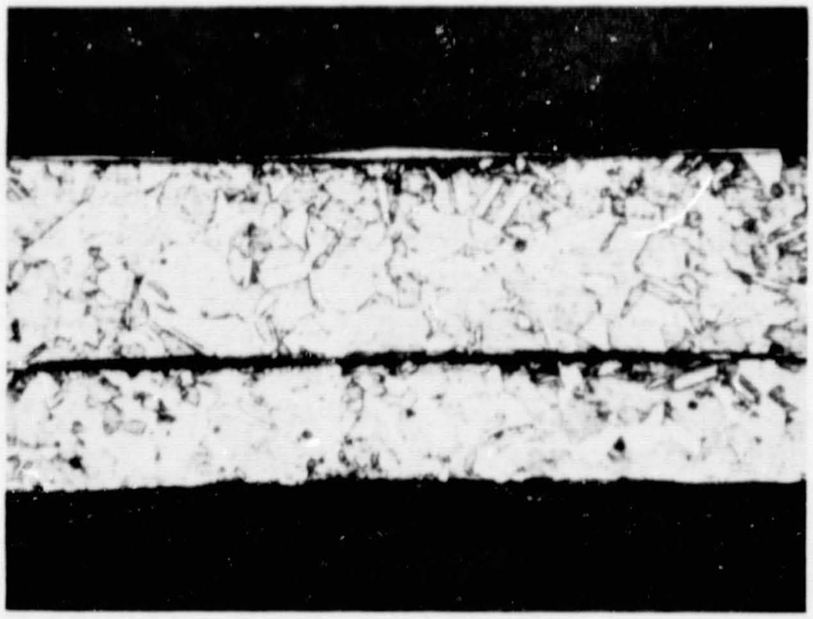


Figure 25. Photomicrograph of a Longitudinal Cross-Sectioned Acceptable Gap Weld

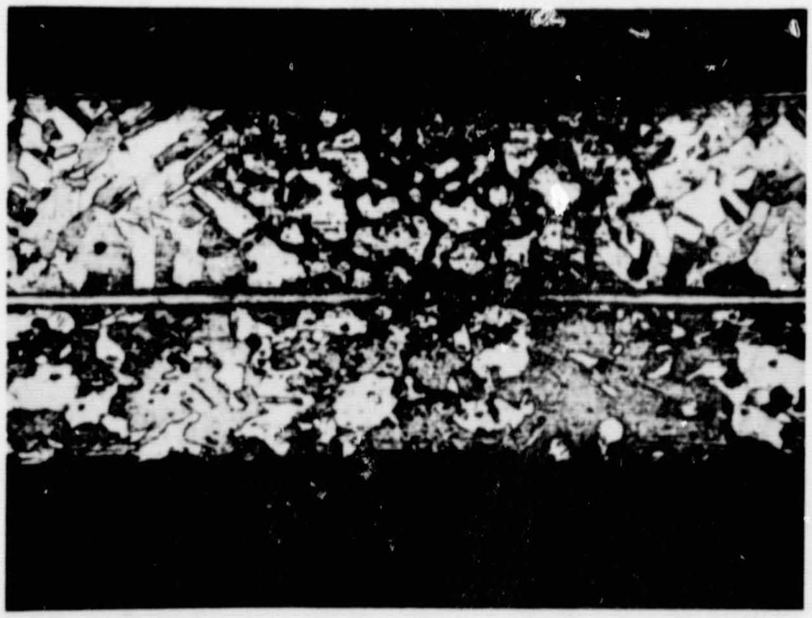


Figure 26. Photomicrograph of a Longitudinal Cross-Sectioned Acceptable Weld

SECTION VII. PROCESS CONTROL

Dynamic and effective process control is the responsibility of all concerned, especially the design, manufacturing, and quality control organizations. Aspects of process control include considerations of equipment, receiving inspection, and personnel training.

A. EQUIPMENT

Equipment variables must be specified prior to the establishment of the weld schedule. After the weld schedule has been established these variables must be held constant in order to assure weld repeatability. Weld circuit resistance, pulse characteristics and duration, and pulse amplitude are some of the parameters of prime importance. Equipment manuals generally outline steps to be taken in measuring capacitance, pulse characteristics and duration. Also, Procedure MSFC-PROC-429 further pinpoints equipment control requirements.

The resistance of the weld circuit has been covered in section II. Any change in weld circuit resistance produces a corresponding change in energy in the weld zone. Therefore, once a welding system has been set up, all of the following parameters should be maintained and held constant.

a. Interconnecting cabling lengths and size.

b. Electrode holder length and size.

c. Electrode material, configuration, and tip size.

d. Contact resistances.

The contact resistances are frequently subjected to various changes due primarily to corrosion or changes in tension of connections. All connections should be inspected at frequent intervals for corrosion and tightness.

The electrodes should be burnished parallel to the electrode width. See figure 7. Burnishing in any other direction or in circular motion only tends to "roll" metal particles on the electrode edges and sides, thereby changing the gap width. In the case of split electrodes,

the metal particles become embedded in the gap material causing possible "shorted" electrodes or a narrower gap width. Reducing the gap width can result in blowout welds or in erratic weld conditions. Electrodes should be frequently inspected and cleaned and should not be allowed to become "mushroomed" as illustrated in figure 27.

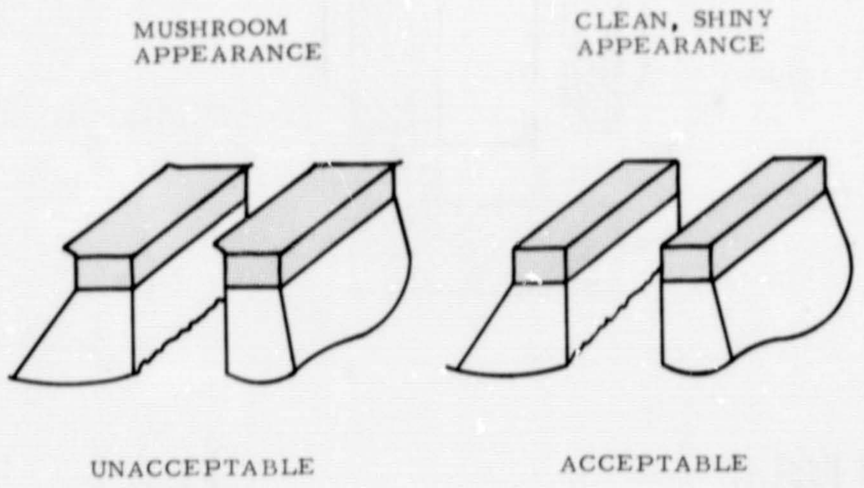


Figure 27. Electrodes

B. RECEIVING INSPECTION

The receiving inspection should process all flat packs, devices, and printed wiring boards and inspect them for defects. The inspection should include:

a. A visual examination for nicked leads and nicked conductors on printed wiring boards and for other visible defects.

b. Functional test flat packs and devices for serviceability and for operation within specified tolerances.

c. An analysis of the composition of the lead and conductor materials, including gold plating thickness.

The composition of the lead and conductor materials may be determined by chemical analysis and the weldability may be determined by welding them in accordance with the applicable weld schedule. The welded test samples are pull tested and these pull test results compared with those strengths specified by the weld schedule.

Leads of flat packs and other devices should be preformed such that the lower portion of the leads are at the plane of the lower portion of the component body. Also, the bends should be made a sufficient distance away from the body to preclude the possibility of fracturing the hermetic seal. Figure 28 illustrates a lead forming tool.

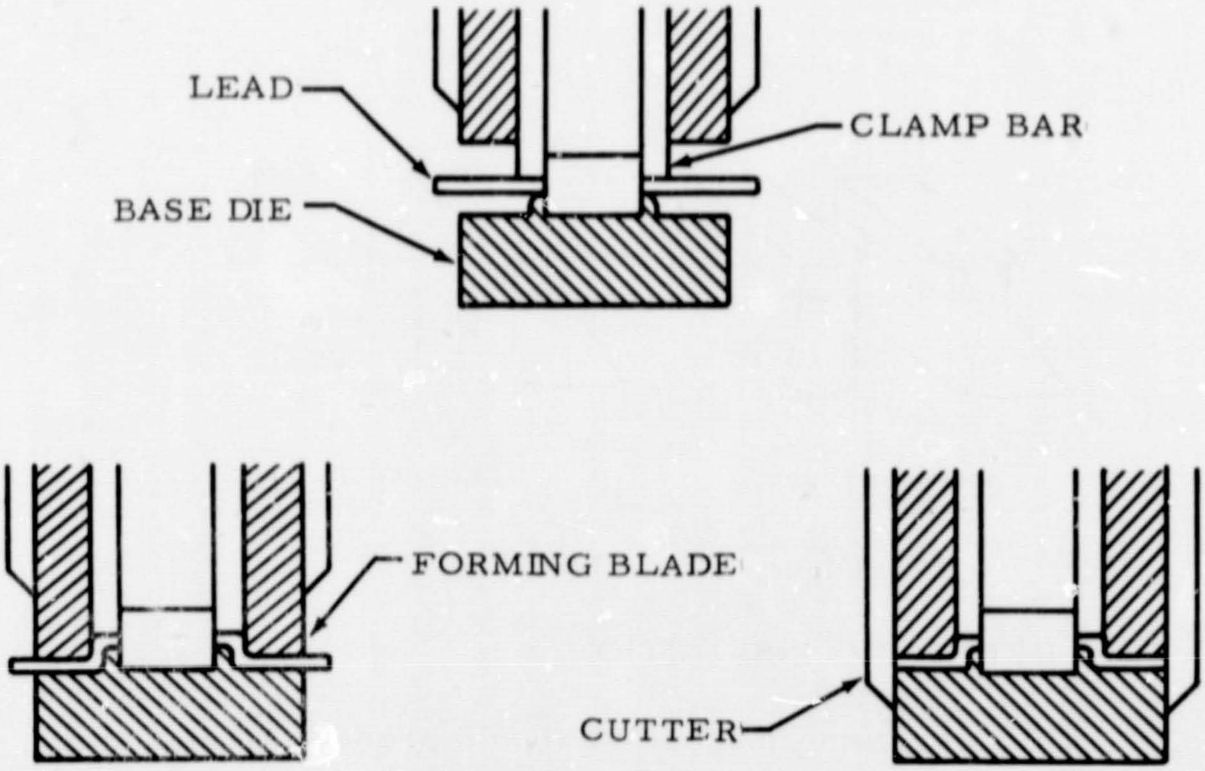


Figure 28. Flat Pack Lead Forming

C. PERSONNEL TRAINING AND OTHER CONSIDERATIONS

There are three general categories of personnel that are directly concerned with the welding process control. These are the welding line supervisor, the weld assembler/operator, and the weld inspector. The distinction among them is the degree of responsibility and level of knowledge of the weld process which is required of them.

The welding line supervisor supervises the welding operation and should have a sound background in the theoretical and practial applications of welding.

The responsibilities of the assembler/operator category personnel are generally limited to:

a. Assembly of basic elements of the package.

b. Welding.

c. Minor cleaning and burnishing of electrodes.

The training of the assemblers/operators should be primarily practical and basic theory.

The inspection personnel should receive a complete training in practical as well as theoretical aspects of both the resistance spot welding and parallel gap welding applications.

The welding area environment should be regulated with regard to both the temperature and the humidity, not only for the comfort of the personnel but also as an aid in process control.

Many companies concerned with the welding operation have attributed erratic welding equipment performance to changes in relative humidity above 55 percent. It is therefore recommended that the relative humidity of the welding area be regulated to 55 $\pm$ 5 percent.

The temperature of the welding area should be controlled at a constant, comfortable working level. Capacitance in the power supply capacitor bank increases with temperature, and if temperature is permitted to fluctuate, a variation in the weld quality will result.

The iso-strength diagram or the weld schedule (figure 13) is an important tool in process control, because the operating parameters selected set up the initial criteria for a particular material combination. All pertinent characteristics should be recorded on the iso-strength diagram to aid manufacturing personnel and inspectors in determining when the process is in control. All records related to the weld process should be kept on file as references for use in process control.